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EVALUATION OF A HAND-HELD FRICTIONAL STRAIN GAUGE(U)

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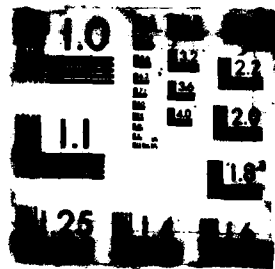
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MELBOURNE, VICTORIA

Aircraft Structures Technical Memorandum 476

EVALUATION OF A BANT-BELD
FRICTIONAL STRAIN GAUGE (U)

by

M.G. Schinca and J.G. Sparrow

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Aircraft Structures Technical Memorandum 476

**EVALUATION OF A HAND - HELD
FRICTIONAL STRAIN GAUGE (U)**

by

M.G. Stimson and J.G. Sparrow

SUMMARY

A system has been implemented at ARL for obtaining strain amplitudes using a commercially available hand applied strain gauge. The gauge measures strain when applied by hand to a cyclically loaded flat surface with the correct normal force to ensure that slipping does not occur. A gauge holder is supplied to transmit the normal force through the gauge to the test piece.

This document describes the tests done to demonstrate the system capabilities and calibrate the gauge. It was found that accuracy and repeatability were comparable with bonded strain gauges for loading frequencies from 0.1 to 25 Hz. Similar results were found when random loading was applied with excellent response observed up to 100 Hz. Strain amplitudes up to $\pm 0.2\%$ elongation were successfully measured and it was shown that the surface need not be very clean for correct performance at lower strains.



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1. INTRODUCTION

The Aeronautical Research Laboratories (ARL) Structures Division has acquired a commercially available instrument for obtaining strain values from a cyclically loaded flat surface. This strain gauge has the advantage over a conventional bonded gauge in that it can be applied with little or no preparation time.

This advantage makes it useful in conjunction with the SPATE 8000 thermal stress pattern imager which is usually calibrated by obtaining a cyclic strain reading from within the field of view of the article under test. Use of a conventional bonded gauge on the article necessarily obscures some area within the field of view.

Experiments were performed to show that an electrical signal linearly dependent on the strain amplitude could be obtained. The accuracy and repeatability of this signal was checked for different frequencies and effects of surface cleanliness.

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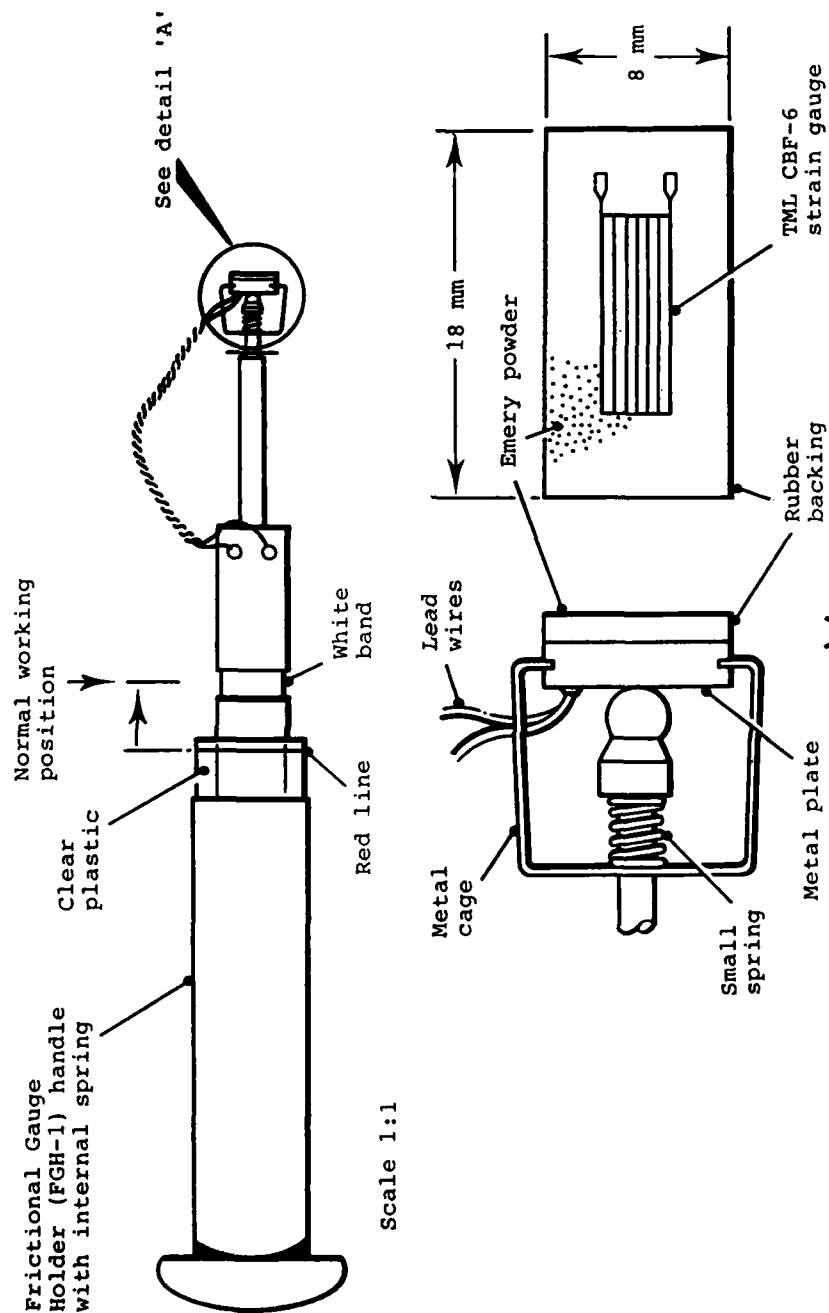
2. THE INSTRUMENT

The instrument is a 10mm gauge length strain gauge mounted on a pad which is held in a Frictional Gauge Holder (FGH-1) manufactured by Tokyo Sokki Kenkyujo Co. Ltd. (TML). The TML designation for the gauge is CBF-6. The configuration is shown in Figure 1. The "hand-held" strain gauge (HHS) is a typical 120 Ω , copper-nickel foil gauge bonded to a rubber rectangular backing pad. The emery powder cemented over the gauge provides a high coefficient of friction. The higher the coefficient of friction the greater the cyclic strains that can be transmitted when a force normal to the surface is applied through the handle and spring plunger. Strains are completely transmitted up until there is slipping between specimen surface and gauge. The manufacturer [1] specifies $\pm 0.1\%$ strain to be the limit of accurate strain measurement.

Consistency of the normal force and hence, the maximum tangential reaction, is achieved by steadily maintaining the red line on the handle within the white band around the stem as shown in Figure 1. This results in a normal force of between 28 and 39 newtons.

It was sometimes convenient to provide this small force by wrapping rubber bands around the specimen and the FGH-1. However, excellent strain signal stability could be achieved by hand.

The emery surface and gauge assembly was found to be easily damaged with resulting degradation of performance. Hence, reasonable care must be taken in handling the instrument.



Third angle projection

Scale 1:4

FIG. 1. THE INSTRUMENT

3. MEASUREMENT SYSTEM

The data acquisition equipment consisted of a SOLARTRON 1250 Frequency Response Analyser (FRA), a testing machine load cell and a strain gauge amplifier with power source. A schematic diagram of the system is shown in Figure 2.

The CBF-6 gauge was connected to the amplifier in the standard Wheatstone bridge arrangement for bonded strain gauges. This involves 3 other $120\ \Omega$ dummy gauges used as resistors. The Wheatstone bridge output was boosted by approximately 3 dB and connected to channel 1 of the FRA.

The analysis carried out by the FRA was merely an integration over a number of cycles of the signal being received at the loading frequency. Synchronisation of the analyser with the FRA crystal oscillator, which was providing the loading reference signal, ensured only signals at that frequency were integrated and displayed. The FRA provided this clean sinusoidal driving signal to the loading machines since it was found that the non-crystal oscillators in the machine function generators could not show the required frequency stability.

The FRA also displayed the phase of the HHSG and the load cell relative to the driving signal it was providing. The difference between these angles is the lag between the load cell and the HHSG which includes any effect from the amplifier. It is not necessary to record the phase angle to use the HHSG, but it was recorded during this evaluation to confirm that no resonances occurred under different uniform cyclic loads and frequencies.

Random loading was applied to the specimen by feeding amplified white noise from a HP 3552A Spectrum Analyser (SA) to the Materials Testing System Corporation (MTS) testing machine control unit. The rms value of the applied load was controlled by the MTS span control knob. However, the numerical value of the load was not explicitly related to this control setting because of the random driving signal.

The load cell and amplified HHSG spectra were displayed on the screen of the SA and dumped to a HP 7090A Measurement Plotting System. This effectively showed the response of the HHSG to the load being applied. The SA was also able to obtain and plot the magnitude and phase of the transfer function between the load cell and the HHSG

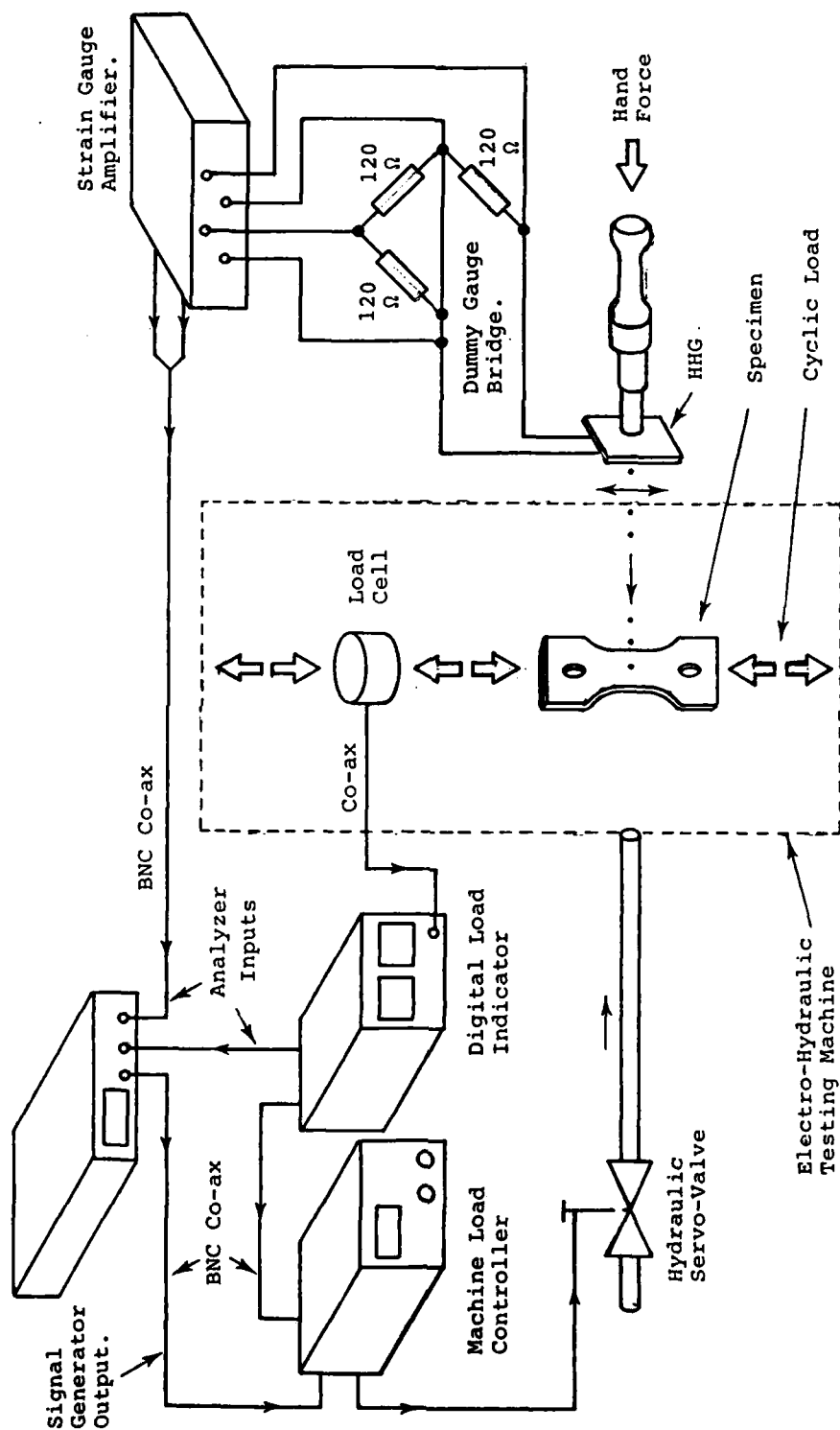


FIG. 2 SYSTEM DIAGRAM.

4. RESULTS

4.1 Instron Experiments

The first successful use of the HHSG was with a flat specimen of aluminium alloy (2024-T4) loaded by the Instron 250 kN capacity servo-hydraulic testing machine.

The FRA generator signal directly controlled both the amplitude and mean load. Mean stress was constant, with 700 mV of DC offset producing 65.2 MPa in the specimen.

Strain amplitude range for these tests was from ± 130 microstrain to ± 1007 microstrain whilst frequencies of 0.1, 1.0 and 5.0 Hz were used. For one of the runs the amplitude was constant whilst the frequency was stepped up from 0.1 Hz to 25 Hz. In each run a note was made of the HHSG and load cell rms voltages displayed on the FRA.

The run performed at 5.0 Hz with a clean specimen surface was taken as the calibration run for the work done in the INSTRON 250 kN machine. Table 1 shows the predicted values of strain amplitude and the signal achieved from the HHSG in columns 3 and 4.

Since the digital display of load as percent of capacity on the INSTRON provided only 2 decimal places, a linear regression of indicated load against the selected FRA generator amplitude was performed. The equation of the resulting line is given in Table 1, Note 1. This enabled a reduction in the rounding errors for new values of applied cyclic load obtained with that equation. These values, shown in column 2, were then easily converted to strains since the specimen was under uniaxial tension - tension.

Regression of column 3 data with column 4 gave the following equation for obtaining applied strain from HHSG reading.

$$\Delta\text{Strain} = 1.089 \times R + 22.184 \quad (1)$$

where R = HHSG reading of rms millivolts

ΔStrain = half peak to peak measured strain in microstrain

The calibration line represented by this equation can be seen in Figure 3.

Using the above calibration, ΔStrain values were obtained from measured voltages for another run performed at 1.0 Hz and compared with the values of ΔStrain actually applied. The comparison is shown in Table 2 and in Figure 4. Both these figures show very good linearity to the limits of accuracy of the experiments. Also, by obtaining a slope of 45 degrees in Figure 4 from the calibrated measured strains versus the applied strains, we see that the same calibration line equation as the 5.0 Hz run applies. This evidence indicates frequency independence and excellent repeatability.

Also, amplitude increasing runs similar to those above were performed at different frequencies, such as 7.0 Hz and 20.0 Hz.

The effect of frequency was investigated by performing a run where the frequency was incremented from 0.1 Hz to 25.0 Hz whilst the amplitude control was left untouched. Inevitably, the load response of the servo-hydraulic INSTRON machine dropped off with increasing frequency. However, as shown in Figure 5, the ratio of measured to applied cyclic strain remains constant as loading frequency is increased.

As before, measured HHSG signal was converted to strain using equation (1) and the predicted strain found from the applied load.

TABLE 1. Hand-Held Gauge Calibration Data

Specimen: 2024 aluminium alloy of rectangular cross-section.
Machine: INSTRON 250 kN electro-hydraulic.
Frequency: 5.0 Hz FRA integration time: 10 sec.
FRA generator bias: 700 mV (mean load = 17.5 kN)

FRA Generator Output	Load Cell Indicated Amplitude ⁽¹⁾	Calculated Strain Amplitude ⁽³⁾	Raw HHG Amplitude
(mV) RMS	(kN) ⁽²⁾	($\mu\epsilon$) ⁽²⁾	(mV) RMS
100	3.09	192	159.2
200	5.97	371	314.9
300	8.85	550	488.1
400	11.73	728	660.3
500	14.61	907	804.0
400	11.73	728	651.8
300	8.85	550	481.3
200	5.97	371	313.6
100	3.09	192	158.8

Notes :

1. Load cell indicated amplitude, (Y), in column 2 obtained by regression of raw values with FRA generator output, (X).

$$Y = 2.88 \times 10^{-2} X + 0.210$$

2. These cyclically varying quantities are measured as half the peak to peak value.
3. Specimen area = 230 mm²
Young's modulus = 70.2 x 10⁹ Pa.

TABLE 2. Comparison of applied Strains with HHSO Calibrated Strains

Specimen: 2024 aluminium rectangular cross-section
Machine: INSTRON 250 kN electro-hydraulic.
Frequency: 1.0 Hz FRA integration time: 10 sec.
FRA generator bias: 700mV

Regressed Indicated Load (kN) (2)	Calculated Applied Strain ($\mu\epsilon$) (2)	Calibrated HHSO Strain Amplitude ($\mu\epsilon$)
2.113	131	134
3.871	240	244
5.629	350	353
7.386	459	463
9.114	566	571
10.902	677	682
12.660	786	792
14.413	896	899
16.175	1005	1008
14.418	896	894
10.902	677	679
7.386	459	464
3.971	241	245

Notes :

1. Regressed indicated load obtained from equation:

$$\text{Load} = 0.0352 \times \text{FRA voltage} + 0.355$$

2. These cyclically varying quantities are measured as half the peak to peak value. FRA voltage is in mV (RMS)
3. HHSO signal (mV), converted to strains ($\mu\epsilon$), using the calibration equation :

$$\text{Strain} = \text{HHSO signal} \times 1.089 + 22.184.$$

4. Specimen area = 230 mm², Young's modulus = 70.2 x 10⁹ Pa.

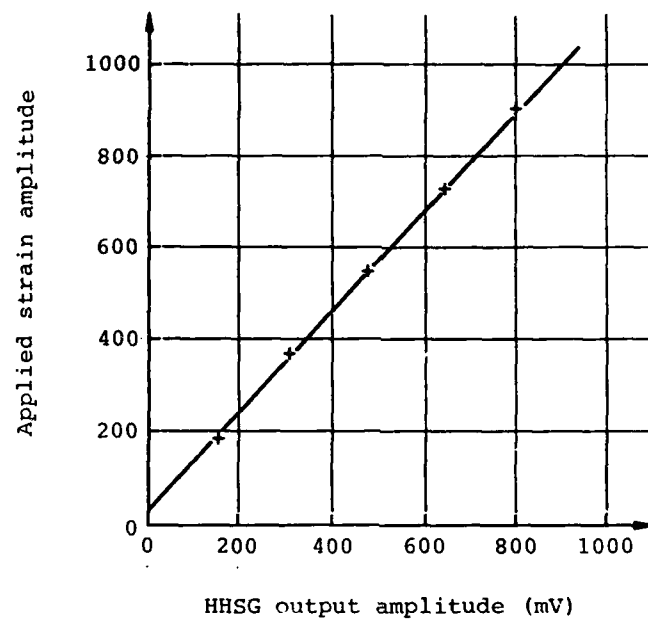


FIG. 3. HHSG CALIBRATION LINE FOR INSTRON 250 kN MACHINE AT 5.0 Hz

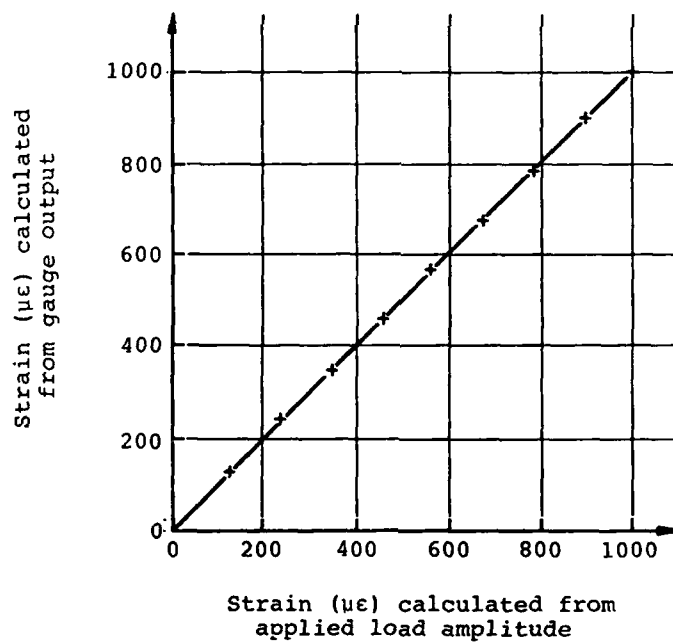


FIG. 4. HAND-HELD GAUGE STRAIN OUTPUT VS APPLIED STRAIN

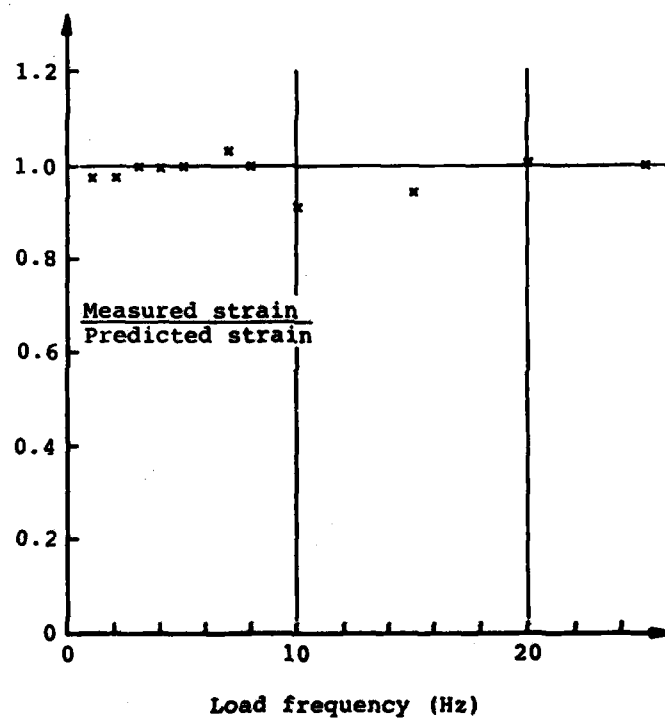


FIG. 5. FREQUENCY EFFECTS

4.2 MTS Experiments

Testing machine availability problems meant experiments continued some time later on a different machine. The specimen was again a 2024 aluminium alloy dog bone and was loaded through the same gripping system as in the INSTRON experiments.

The difference between the clean surface (Table 3 and Figure 6), and the greased surface (Table 4 and Figure 7) was so small they needed to be plotted on different graphs for clarity.

In order to investigate the surface condition effects, SHELL "ALVANA" type light grease was applied. The results presented here are for runs with only a thin smear of grease.

At amplitude levels above 1800 microstrain the signal immediately after application of the HHSG is up to 8% less than the calculated applied strain amplitude. During several periods of integration, of 10 seconds each, the signal climbed with decreasing rapidity until it stabilizes at a value which is only slightly less than could be expected from the experimental errors. As can be seen from Figures 6 and 7 the stabilised readings did not differ from the correct value by more than 10 mV in 500 mV or 2%.

This phenomenon was present when the specimen was clean, only becoming more pronounced once several smears of grease were applied. This means that a small amount of grease on the surface does not significantly affect the gauge response. More grease was applied for later runs but the change in signal did not increase so those results are not presented.

Since low initial readings for Δ strain only appeared at high strain we surmise that slipping is occurring which is causing small temperature rise. A temperature rise at the gauge will cause a proportional increase in strain reading due to the temperature sensitivity of the gauge. The above explanation of this phenomenon also accords with the observed decrease in the rate of signal change as the interface between the gauge and surface achieves heat flow equilibrium.

These tests did not allow an investigation of higher strain amplitudes because the specimens available were too large for the dynamic capacity of the MTS machine.

For these MTS experiments both the load cell and HHSG phase lag relative to the generator driving signal were noted from the FRA display panel. For the 5.0 Hz runs (both clean and greased) the phase lag of the HHSG from the load cell was less than 1 degree and decreased at larger load amplitudes. Phase lag of both transducers from the FRA was significantly greater at 20.0 Hz than at 5.0 Hz, but the HHSG lagged the load by only 2.0 to 3.0 degrees.

The results for the 20.0 Hz runs are not presented here since they showed no new effects compared to those at 5.0 Hz. Also, the MTS maximum load decreases to approximately ± 35 kN at 20.0 Hz which eliminated the area of real interest.

TABLE 3. CLEAN SURFACE CALIBRATION DATA

Specimen : BP46BC2 Material : 2024 - T4 aluminium alloy
Machine : MTS 50 kN Loading Frequency : 5.0 Hz

Indicated Load Amplitude	Calculated Strain Amplitude	Measured H.H.G. Signal
half peak - peak (kN)	half peak - peak ($\mu\epsilon$)	RMS (mV)
2.48 4.94 7.40	321 639 956	83.2 164.7 243.5
9.88 12.37 14.79	1277 1598 1912	318.7 400.5 460.0
" 17.28 "	" 2233 "	475.0 529.0 540.0
14.79 9.84 4.93	1912 1272 637	467.3 321.0 163.2

N.B. A similar run was performed at 20 Hz. However, machine capacity was reached at 1587 $\mu\epsilon$

TABLE 4. GREASED SURFACE CALIBRATION DATA

Specimen : BP46BC2 Material : 2024 - T4 aluminium alloy
Machine : MTS 50 kN Loading Frequency : 5.0 Hz

Indicated Load Amplitude	Calculated Strain Amplitude	Measured H.H.G. Signal
half peak - peak (kN)	half peak - peak ($\mu\epsilon$)	RMS (mV)
2.40 4.88 7.44	310 630 961	79.3 161.1 242.0
9.89 12.41 14.83	1278 1604 1916	320.0 397.6 469.0
" 17.28 "	" 2234 "	470.0 508.5 540.2

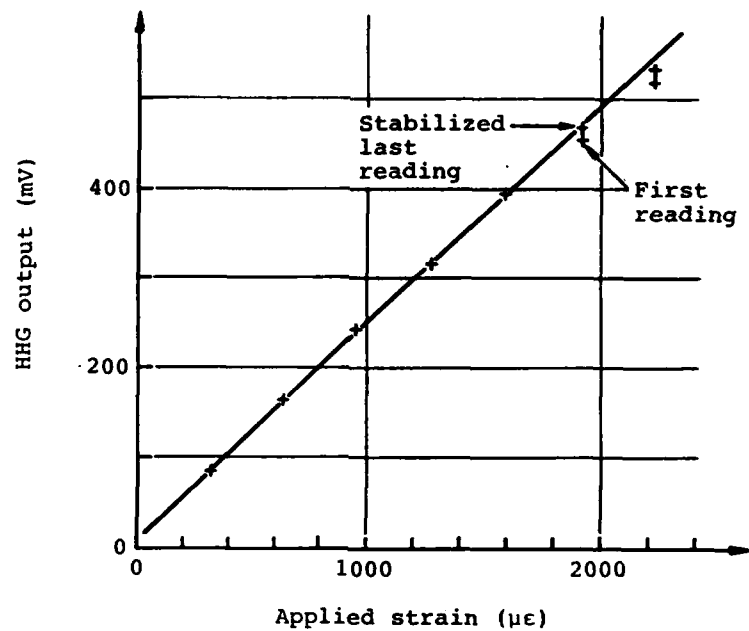


FIG. 6. CLEAN SURFACE, ALUMINIUM SPECIMEN CALIBRATION LINE FOR 5.0 Hz

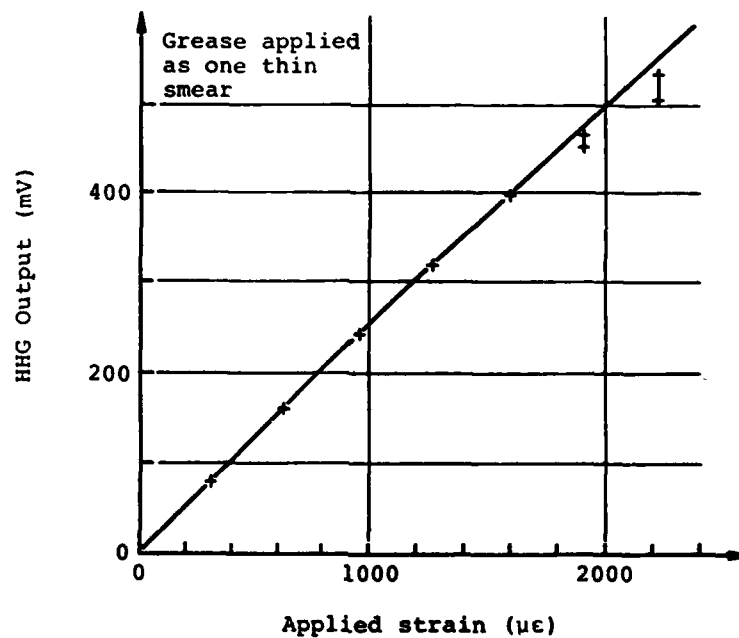


FIG. 7. GREASED SURFACE, ALUMINIUM SPECIMEN CALIBRATION LINE FOR 5.0 Hz

4.3 Random Loading Experiments

Two runs were performed with the HP Spectrum Analyzer (SA) providing the white noise driving signal as described in Section 3. Only one set of results is presented here in Figures 8 and 9 for frequencies from 0 up to 100.0 Hz. There are two input channels on the SA. The channel connected to the load cell had a sensitivity of 3.0 volts with 10 mV per division of the display screen. Channel B connected to the amplifier for the HHSG was set to 0.3 volts sensitivity and 1.0 mV per division.

Both the spectra of Figure 8 and the transfer function graph of Figure 9 were constructed from 16 rms averages of the incoming data with a Hanning passband shape selected. The phase difference graph, (load - HHSG), was displayed at 50 degrees per division.

Figure 8 shows that a small load amplitude was applied so that the MTS machine could cope with the highest frequencies in the random noise supplied. The machine can normally only manage 35 kN at 20.0 Hz with uniform cyclic loading.

A comparison of the spectra shows clearly that the HHSG is faithfully responding to the applied load until over 100.0 Hz. This is confirmed by the uniform transfer function. The peak at the centre is possibly an effect of the small 50.0 Hz mains supply noise which is known to be present in the load cell output. A small increase in the phase difference occurs over the measured range.

The Spectrum Analyser is able to show values of spectral amplitude, transfer function amplitude or phase as a marker is moved along the frequency axis of the display screen. With this feature it is possible to calibrate the HHSG as was done for the uniform cyclic loading tests earlier.

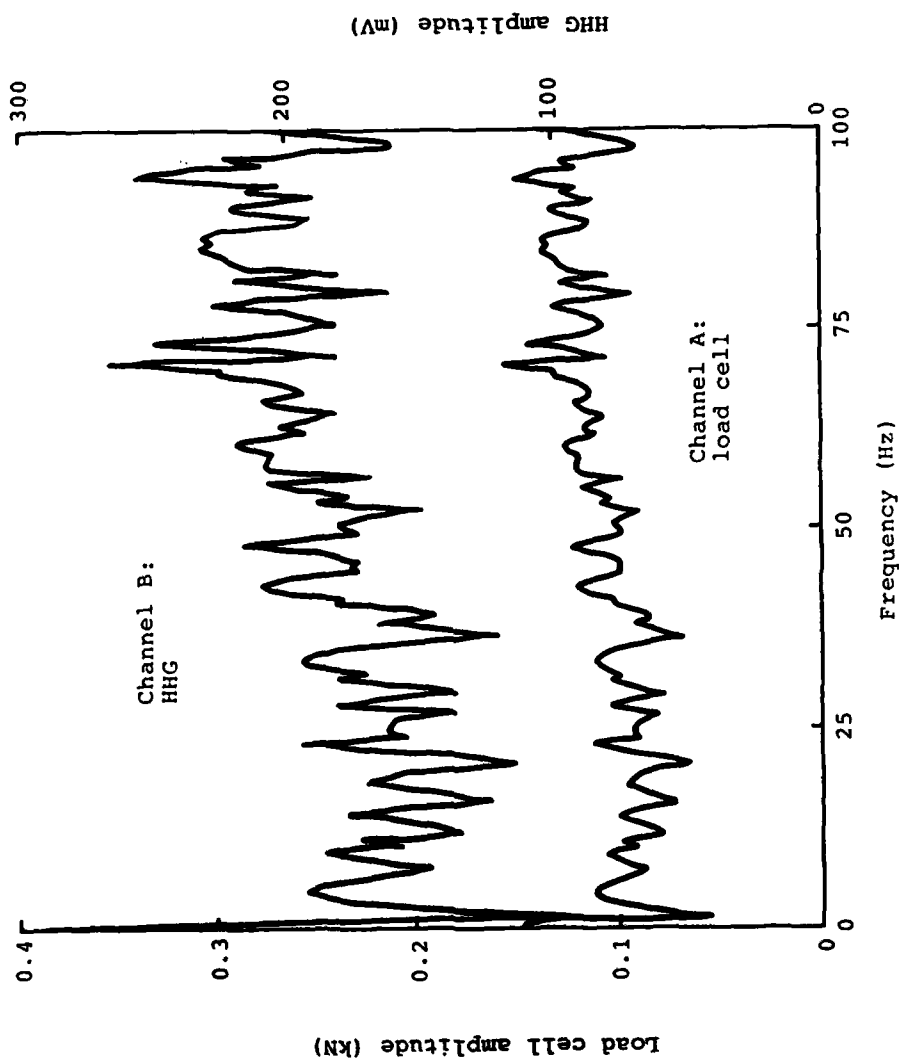


FIG. 8. RANDOM LOADING SPECTRA OF HHG AND LOAD CELL

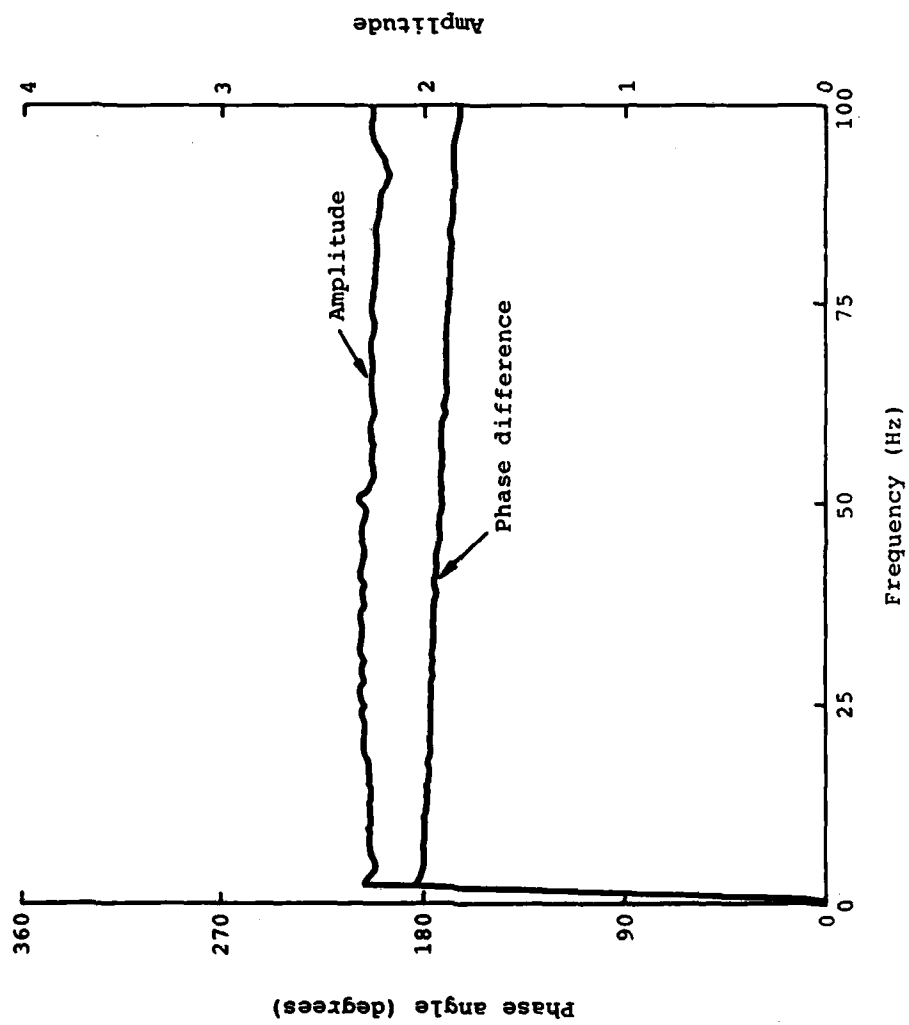


FIG. 9. LOAD CELL TO HHG TRANSFER FUNCTIONS

5. CONCLUSION

The experiments performed to date verify that the Hand-Held Strain Gauge system works well for strains less than 2000 microstrain. This is approximately half of the yield strain for the aluminium alloy used. At and above that level, slipping of the gauge on the surface results in under reading of the applied strain. Frictional heating due to this slipping, however, is thought to counteract this effect giving a reduced error in the HHSG signal after it has steadied.

At amplitude levels above 1800 microstrain the signal immediately after application of the HHSG is significantly less than predicted due to relative slipping. It increases with decreasing rapidity until it stabilizes at a value which is only slightly less than could be expected from the experimental errors. However, this effect does limit the maximum strain amplitude at which accurate readings can be maintained to 2000 microstrain.

The surface cleanliness has been shown to have only a small effect on the performance by increasing the departure from linear response which the gauge shows at higher strain amplitudes. The surface does not, however, have to be scrupulously clean to achieve accurate results since it was only after the application of several thin smeared layers of grease that this performance degradation was noticed.

Frequency does not appear to affect the gauge significantly although the MTS testing machine was not able to provide the higher loads at higher frequencies required to fully test this aspect.

This evaluation has demonstrated that the HHSG is expected to be very useful during fatigue tests because accurate, quick and inexpensive strain readings can be taken from many varied locations on the structure. Stress concentrations and positions for fixed strain gauges can now be determined experimentally in the preliminary stages of a test.

The random loading sequence experiments demonstrated that the HHSG responds very well up to at least 100.0 Hz. This should be adequate for use in providing the reference signal to SPATE for a planned investigation as to whether that instrument can be extended to deal with random loading rather than purely uniform cycling. The only proviso is that the strain levels be low enough to be in the linear response region.

ACKNOWLEDGEMENTS

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David Smith and Philip Ferrarotto are gratefully acknowledged for their professional electrical expertise applied to the development of the HHSG circuits.

REFERENCES

1. TML, "TML Strain Gauges Catalogue", TML pamphlet E-101N. Tokyo, Tokyo Sokki Kenkyujo Co. Ltd., pages 4, 5 and 16.

APPENDIX

HHSg to Amplifier Connections

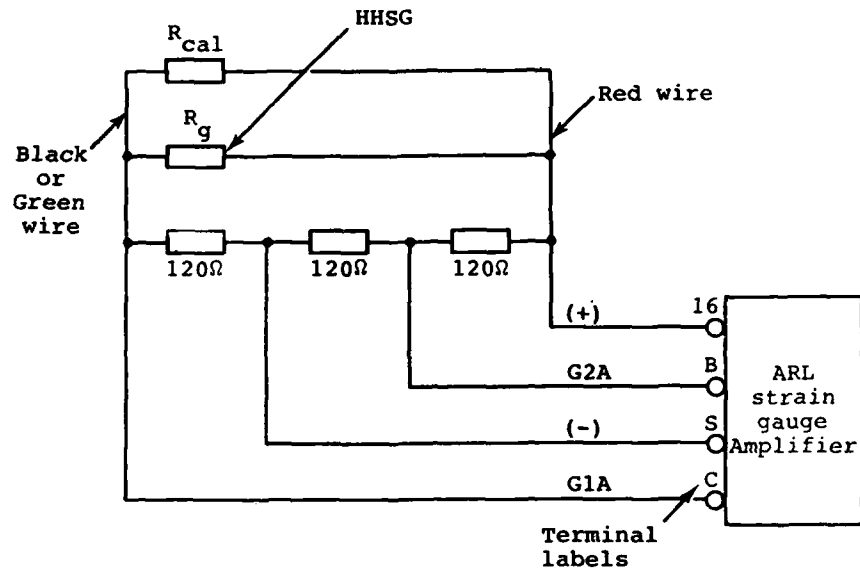


Figure 10. Hand-Held Strain Gauge Connections

Amplifier Gain Determination

Without calibration resistor the FLUKE volt meter displayed $V_{in} = 1.56$ mV across terminals "B" and "C" and amplifier output was $V_{out} = 1.893$ V.

With the calibration resistor in parallel with the HHSg, the simulated strain from this is given by ;

$$R_{cal} = \frac{R_g}{K \epsilon BF} - R_g$$

where

R_{cal} = calibration resistance

BF = Bridge factor = 1.

R_g = resistance of individual dummy gauges = 120 ohm

K = gauge factor = 2.06

ϵ = applied Δ strain

For a typical applied strain of 1000 microstrain we obtain $R_{cal} = 58.13$ kohm. Simulating this with 58.2 kohm resistance in parallel with the HHSg, we measured the voltages mentioned above to be $V_{in} = 0.35$ mV and $V_{out} = 3.383$ V. Therefore ,

$$\begin{aligned} \text{Amplifier Gain Factor} &= \log_{10} \left(\frac{\Delta V_{out}}{\Delta V_{in}} \right) \\ &= 3.09 \text{ dB} \end{aligned}$$

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16. ABSTRACT (CONT.)

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